AN INAUGURAL ESSAY

ON THE EFFECTS PRODUCED BY

AIR UPON LIVING ANIMALS.

SUBMITTED TO THE EXAMINATION OF

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(PRO TEMPORE)

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On the 5th day of June 1805.

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Of Alexandria, in the District of Columbia.

HONORARY MEMBER OF THE PHILADELPHIA MEDICAL SOCIETY.

They wish to live,
To view the light of Heav'n, and breathe the vital air. *Dryden.*

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1805.

TO

DOCTOR JAMES CRAIK,

Of Alexandria;

Whose inestimable Talents as a Physician, and amiable Virtues as a Man,

HAVE LONG ENDEARED HIM TO HIS FELLOW-CITIZENS;

THIS ESSAY

IS INSCRIBED,

AS A SINCERE TRIBUTE OF ESTEEM AND FRIENDSHIP,

BY HIS FORMER PUPIL,

THE AUTHOR.

J W Mendenhall from

his friend the

author

TO THE

MANAGERS AND PHYSICIANS

OF THE

PENNSYLVANIA HOSPITAL;

WHOSE

DISINTERESTED AND ACTIVE EXERTIONS

IN ALLEVIATING HUMAN MISERY,

REFLECT HONOUR ON OUR COUNTRY:

THIS IMPERFECT ESSAY

IS RESPECTFULLY INSCRIBED,

BY THEIR FRIEND AND PUPIL,

THE AUTHOR.

**** *A considerable part of the time allowed for preparing this Essay was entirely lost through indisposition; another part was necessarily expended in performing the duties of House Surgeon to the Pennsylvania Hospital. To the candid and intelligent reader, no further apology need be made, for the very superficial manner in which the subject has been treated. Whoever has been engaged in an inquiry of this nature must be sensible, that it is absolutely necessary to be possessed of the most uninterrupted leisure, before any material progress can be made.*

INTRODUCTION.

ONE of the earliest acquirements of the human mind, is a power of distinguishing the actions of living animals from the motions of inanimate matter. We cannot recollect that period of our infancy when we were entirely ignorant of all the characteristics of vitality. The eagerness of brutes in the pursuit of pleasure, their caution in avoiding pain, leave no room to doubt, that their voluntary motions like ours are the result of, and are accompanied by sensation. The growth or continual increase of bulk in young animals, is another peculiarity of living beings which cannot escape the attention of the most superficial observer. But to grow is not the exclusive privilege of animals—plants too possess this attribute of vitality.

Thus from a few facts which are self-evident and familiar to every inquirer, even in the infancy of reason, we may deduce this general conclusion: that vital action is governed by laws entirely different from those which regulate the motions of inanimate matter. This is a truth which we should ever bear in mind in all our physiological investigations.

We do not mean to insinuate that the common laws of nature have no relation to living matter. The effect produced by gravitation upon the circulation of the blood is well known. As this effect is mechanical, the inconvenience that would result from it is obviated by a mechanical contrivance. We allude to the valves in the veins, particularly to those of the lower extremities. Each valve sustains a column of blood, and prevents it from gravitating upon the contents of the inferior part of the vein. Had the veins been endowed with a contractile power equal to that possessed by the arteries, this valvular structure would perhaps have been unnecessary; but such a provision would have induced a useless expenditure of vital energy. In the arteries which supply the bones of the leg with blood, we have a beautiful example of the attention which nature has paid to the laws of gravitation. These vessels always have a downward direction which very much facilitates the flow of their contents. The winding course of the vertebral and carotid arteries in man, as well as the elegant net-work in the same vessels of the lion and other animals, are no less worthy of our admiration. This peculiar structure was intended to prevent a too sudden and violent impetus of the blood, upon that important and delicate organ the brain.

We are much indebted to the cultivators of chemical science for the light they have thrown on some of the functions of living animals. The solution of food in the gastric juice, and the union of blood with air in the lungs, are in part true chemical phenomena.

We adduce these facts to shew, that the laws of the animal economy harmonize with the general laws of nature; but when we endeavour to explain the circulation of the blood, the contraction of the minutest fibre, or the secretion of the simplest fluid, upon mechanical and chemical principles, how feeble is their aid—how futile the attempt!

Every part of the animated machine is dependant upon some other for its health and life. This is an incontrovertible truth, and has long been considered as an axiom in physiology. The venom of the viper, injected by the Abbe Fontana into the jugular vein of a rabbit, produced instant death, and a coagulation of the blood. The same active poison, when added to the blood as it flowed from the vein of another rabbit, produced no change. This experiment shews the impropriety of admitting any physiological fact, which is not the result of an observation or experiment upon a living animal.

It was thought necessary to premise these general remarks before proceeding to the immediate subject of this Essay. They are offered as an apology for passing over in silence, many experiments which have been made with a view of ascertaining the effects produced by air and other substances, on blood drawn from the body.

In the First Section, we will endeavour to give a very brief historical sketch of the facts relating to the influence exerted by air upon the circulating blood, which were observed previously to the discovery of oxygen gas. In the Second Section, after giving a short account of the analysis of atmospheric air, we will examine the following questions:

I. Does a part of the air inspired unite with the circulating blood?

II. Does the formation of fixed air eliminated from the lungs, depend upon the union of oxygen with carbon, separated from the venous blood?

III. Is respiration essential to the evolution of animal heat?

IV. Does the irritability of the whole system depend upon the influence exerted by air upon the blood?

The Third Section will contain some experiments on incubation.

In the Fourth, we will relate some experiments on the respiration of oxygenated muriatic acid gas.

SECTION I.

THE blood is one of the most important parts of a living animal. Scarcely any healthy change can take place in a solid, except through the medium of this fluid; it conveys heat and nutrition to the whole system.

As the blood acts so conspicuous a part in the maintenance of vital action, it has received the greatest attention from the anatomists and physiologists of every age. Its nature and properties, however, were but little known before the beginning of the seventeenth century, when the illustrious Harvey demonstrated its circular motion. As soon as it was clearly ascertained that the arteries, during life, contained blood instead of air, physiologists were naturally led to compare the arterial blood with that, which even after death, had been always found in the veins. They soon became acquainted with the fact, that venous blood was of a much darker colour than that of the arteries. The experiments of Harvey had proven, that the whole mass of venous blood must pass through the lungs before it can reach the commencement of the arterial system, in the left ventricle of the heart. From these facts, the inference was obvious, that during its passage through the lungs, this vital fluid underwent some very material change. It was still a problem with the physiologists of that day, whether this change was induced by the air inspired, or by the mechanical action of the lungs. With a view of determining this question, "Hooke opened "the thorax of a living animal, cut away his ribs and dia-"phraghm, and took off the pericardium. He kept the dog "alive above an hour, before the Royal Society, by blowing

" fresh air into his lungs with a pair of bellows. He pricked " the outer coat of the lungs with the slender point of a sharp " pen-knife, and with a continual blast, made with a double " pair of bellows, he kept the lungs always distended, and " without motion; and it was observed, that while the lungs " were thus kept distended with a constant supply of fresh air, " the dog lay still, his eyes were quick, and his breast beat " regularly; but upon leaving off blowing, and suffering the " lungs to lie still, the dog presently fell into dying convulsive " motions, and as soon recovered again on renewing the blast, " and supplying the lungs with fresh air."*

This experiment is mentioned by Lower in his Tractatus de Corde, published in 1669. Lower brings forward many objections to an opinion which prevailed in his time, that the red colour of arterial blood was owing to some change induced in it by the action of the left ventricle of the heart. To shew that respiration is the sole cause of this change, he relates the following experiment. After opening at the same time the jugular vein and a large artery of a dog, he put a stop to respiration by passing a ligature round the wind-pipe. The blood which flowed from the divided artery was of the same colour with that which came from the vein. He then opened the thorax of another dog, and kept up a continual artificial respiration; on dividing one of the pulmonary veins, he found the blood of a beautiful vermillion colour.

Boyle, a distinguished philosopher, who lived about the same time with Lower, published an account of his experiments on respiration. He proved that animals can live but a short time when confined in close vessels. Observing that combustion required a continual supply of fresh air, he shewed the "resemblance or analogy between fire and life." He remarked that air was as necessary to the life of fishes as of land

* See a Paper, by Dr. Thornton, in the 18th volume of the Philosophical Magazine.

animals; and brings forward this fact as an objection to the opinion, that the only use of respiration is to cool the blood. But the most interesting observation made by Boyle on this subject is, that the irritability of the heart was increased by respiration. He opened the uterus of a pregnant bitch, and permitted one of the pups to respire for a short space of time. The pulsations of the heart were very evident, and continued to be so nearly eight hours. In those fœtus which had not breathed, the heart contracted but a few minutes after death.

It was reserved for Mayow, who lived in the latter part of the seventeenth century, to explain and extend the discoveries of Hooke, Lower and Boyle. Mayow was perhaps the first who asserted, that the placenta performed a function very similar to respiration, and that the blood underwent nearly the same change in the umbilical vessels of the fœtus, as in the pulmonary veins of the adult. He was in all probability led to adopt this opinion from observing, that the air in the cavity of an incubated egg was not breathed by the chick in ovo, and that this air was in contact with the umbilical arteries. The conclusion deduced by Mayow from an interesting series of experiments, was, that respiration imparts to the blood certain "vital and elastic parts" of the air we breathe, which serve to keep up muscular motion and animal heat.

Thus far physiologists had proceeded in the investigation of this truly intricate subject, before the beginning of the eighteenth century. Although they were almost entirely ignorant of the composition of the atmosphere, yet with respect to the influence exerted by air upon living animals, their discoveries were as important as those of the most fortunate experimentalists of later days.

The experiments and observations of Harvey, Hooke, Lower, Boyle and Mayow, had proven, that respiration imparts to the blood its red colour and power of stimulating the heart and arteries. Their labours had rendered it probable, that a part of the air respired was absorbed by the circulating fluid: and the lungs which, according to the older physiologists, were destined to fan and cool the blood, were now considered as the focus from which the whole system was supplied with heat.

Nearly a century elapsed before any further progress was made in investigating the properties of atmospheric air. That the atmosphere was a compound, and that during respiration its constituent parts were separated from each other, was an opinion adopted by several respectable writers. But it was a doctrine by no means generally received. It was by some considered merely as an hypothesis, and entirely destitute of proof. This class of physiologists, among whom we find the learned and indefatigable Haller, considered respiration as nothing more than an excretory process. They supposed that something was discharged from the blood in its passage through the lungs, which if retained would be injurious to the system.

In the year 1756, Doctor Joseph Black made the first successful attempt to ascertain the changes produced in air by respiration. This able experimentalist examined with great care the gas silvestre of Van Helmont. He found that this gas was generated in large quantities by fermentation and combustion, that it possessed a strong attraction for lime and caustic pot-ash, and that its union with these substances rendered them mild, and capable of effervescing with acids. Hales had shewn, that "breathing through pieces of cloth dipped in an alcaline solution made the air last longer for the purposes of life." This experiment induced Doctor Black to suspect, that fixed air was discharged from the lungs during respiration. By repeating the experiment of Hales it was proven, that caustic pot-ash was rendered mild by the expired air; and on breathing through lime water, the presence of fixed air was evinced by the precipitation of the carbonate of lime. In this manner the analogy between respiration and combustion, first observed by Boyle and Mayow, was rendered very striking by the experiments of Black. "We know not," said this excellent chemist, "how many different airs may be contained in our atmosphere, nor what may be their separate properties,"

SECTION II.

ANALYSIS OF ATMOSPHERIC AIR.

ON the first of August 1774, Doctor Joseph Priestley exposed mercurius calcinatus (red oxide of mercury) to the heat of a burning lens, and received the gas which was discharged from it over mercury.

A candle placed in the vessel containing this gas burned with a vivid and enlarged flame. A mouse introduced into a bell-glass filled with the same air, lived much longer than another mouse confined in an equal quantity of atmospheric air.

While Priestley was engaged in making these experiments, Scheele was prosecuting the same subject with great success. This able chemist placed a mixture of iron-filings and sulphur in contact with atmospheric air in close vessels over water. The diminution of volume which took place shewed that about one-third of the air had been absorbed. On examining the remaining air, he found that it was unfit for the respiration of animals, or for the combustion of inanimate substances.

Before the discoveries of Priestley and Scheele were made known to the world, Lavoisier had directed his attention to the same interesting branch of science. From a number of ingenious and well conducted experiments he concludes, that one hundred parts of the air we breathe are composed of about twenty-seven parts highly respirable and proper for combustion, to which he gave the name of oxygen gas; and seventy-three parts, denominated azotic, which instantly extinguish a taper and are fatal to animal life.*

* From some experiments that have been since made by De Marti and others, it appears that atmospheric air contains 28 per cent. oxygen gas.

The analyses which have been made of the atmosphere at different periods, and in different parts of the world, have always afforded very nearly the same results.

Does a part of the air respired unite with the circulating blood?

That a considerable diminution of volume takes place in the air respired, is a fact which was long since well ascertained. As soon as physiologists became acquainted with the composition of the atmosphere, it was very natural to inquire, what particular part of it disappeared during respiration?

The first experiments which were made with a view of throwing light on this subject proved, that a large proportion of the oxygenous part of the air was consumed. As this consumption of oxygen must vary with the varying states of the system, the results of the experiments, which have been instituted with a view of ascertaining the precise diminution which takes place in the volume of the respired air, must also vary. The experiments of Doctor Goodwin are, perhaps, as accurate as any that have hitherto been made.

The volume of air taken into the lungs at a single inspiration, contained,	*parts.*	The volume of air expelled from the lungs by the next succeeding expiration, contained,	*parts.*
Phlogisticated air (azotic gas)	80	Phlogisticated air,	80
Dephlogisticated air (oxygen gas)	18	Dephlogisticated air,	5
Fixed air (cabonic acid gas)	2	Fixed air,	13

Dr. Goodwin concludes from his experiments, that something pervades the coats of the pulmonary vessels by the force of chemical attraction. " But what it is," says he, " that " pervades the vessels is not yet known: whether some prin- " ciple, separated from the blood be combined with the de- " phlogisticated air, to form fixed air; or whether the dephlo- " gisticated air be decomposed, and a part of it passes into the

" blood, while the other part remains behind in the form of " fixed air; or lastly, whether the dephlogisticated air enters " into the blood in its entire state, whilst the fixed air is sepa- " rated from the vessels."

Lavoisier attributes this loss of oxygen entirely to its uniting with carbon and hydrogene eliminated from the blood. This opinion has been controverted by succeeding inquirers. One objection to Lavoisier's hypothesis, was, that neither carbon nor hydrogen would unite with oxygen at so low a temperature as that of the blood. Girtanner injected oxygenous gas into the jugular vein of a dog; death was produced in three minutes, but the irritability of the heart was increased considerably. From this, Girtanner inferred, that one of the uses of respiration, is, to convey oxygen gas to the arterial blood; but a very different conclusion has been drawn from this experiment by other physiologists. It has been adduced, as an argument in favour of the opinion, that the presence of air in the blood in any form whatever, is incompatible with life.

Air injected into the jugular vein of an animal, invariably produces death, as soon as it reaches the right side of the heart. But the blood in the right side of the heart is not immediately affected by respiration. An experiment performed by Bichat, and related in his excellent work, " Sur la Vie et la Mort," may perhaps throw some light on this subject. He fixed a tube in the trachea of a dog, and adapted to it a large syringe, by which he injected into the lungs a greater quantity of air than they usually contained; the air was then retained in the bronchiæ by closing the tube; the animal immediately became very much agitated; one of the arteries of the leg was then divided: the blood flowing from the wounded vessel was mixed with innumerable bubbles of air. When hydrogene gas was used, Bichat ascertained that it passed through the vessels unchanged, for upon bringing a taper near the orifice in the artery, the bubbles took fire as they escaped. Bichat informs us, that he had frequently repeated this experiment, and that the inevitable effect of it was, the death of the animals on which it was made. Few survived it for a greater length of time than thirty seconds. On examining the vessels of these animals, after death, he generally found the blood in the whole sanguiferous system of a very red colour, and mixed with bubbles of air. In some instances, however, the air did not appear to have proceeded further than the capillary vessels. In these cases, although the circulation continued some time after the experiment was begun, yet the venous blood contained no perceptible bubbles of air, while in the arterial they were very abundant.

The quantity of air thrown into the arteries in these experiments was so great as to destroy all the powers of life. Any foreign matter whatever so suddenly introduced into the blood would have the same deleterious effect. Is it not probable that the arteries, and the blood they contain, have the power of assimilating to their own nature, the small quantity of air which they receive during respiration? Will air when gradually introduced into the arterial system have the same fatal effects as when injected into the veins? With a view of solving this question I opened the femoral artery of a dog, and with a small syringe injected into it about one-eighth of a cubic inch of atmospheric air. A ligature was passed round the divided artery before the syringe was withdrawn. It did not appear that the air was in the smallest degree injurious to the dog. He recovered from the effects of the wound in a few days.

This experiment proves that air even in an elastic state, may exist in the arteries without inducing death. It is also in favour of the opinion that oxygen unites with the blood in its passage through the pulmonary veins. Have we any direct evidence that this union does take place?

" A phial," says Humphrey Davy, " containing twelve cubic " inches, having a pneumatic apparatus affixed to it, was filled

" with arterial blood from the carotid artery of a calf. The " phial was placed in a sand bath of the temperature of 96°, " and the heat gradually and slowly raised. In about ten mi- " nutes the temperature of the bath was 108°, and the blood " began to coagulate. At this moment some globules of gas " were perceived passing through the tube. Gas continued to " pass in very small quantities for about half an hour, when " the temperature of the sand was about 200°; the blood had " coagulated perfectly, and was now almost black: about a " cubic inch and eight tenths of gas were collected in the mer- " curial apparatus; of this, one cubic inch and one tenth was " carbonic acid gas, and the remaining seven tenths phos oxy- " gen."

This experiment is by no means decisive. The blood, while passing into the phial, must have come into contact with atmospheric air. That venous, as well as arterial blood, when exposed to the air, will absorb oxygen, has long ago been clearly ascertained. But the blood, while circulating in the vessels of a living animal, is under very different circumstances.*

When an animal is confined in a close vessel containing oxygen gas over lime-water, the latter rises in the vessel, and becomes turbid. This experiment was first made by Lavoisier; it was repeated by Dr. Higgins, and is related in the minutes of the Society for Philosophical Conversations.

It was the opinion of Priestley, that azotic gas, as well as oxygen, was consumed during respiration. This is rendered

* The opinion that the blood owes its red colour to the union of the phosphorus and iron (which it contains) with oxygen, during respiration, is entirely hypothetical. We are informed by Fourcroy, that the blood of the fœtus contains no phosphorus. I have frequently ascertained that the blood in the fœtus of brutes, at different periods during gestation, acquires a bright red colour, upon being exposed to the air.

very probable by the experiments of Davy: on making a single inspiration of atmospheric air, which consisted of

103 Azotic gas,
37 Oxygen gas,
1 Carbonic acid gas,

he found that the quantity of azotic gas was diminished from one to three cubic inches; that from five to six cubic inches of oxygen had disappeared, and that from 5 to 5.5 carbonic acid was formed. The same diminution of azotic gas took place at each inspiration, when a given quantity of atmospheric air was respired for any length of time.

In all these experiments, the quantity of oxygen gas which disappears, is nearly the same with that of fixed air given out. Thus, in the experiment of Goodwin, thirteen parts of oxygen gas disappeared, and the same quantity of fixed air was discharged from the lungs. In the experiments made by Davy, the quantity of fixed air expired, was nearly equal to that of oxygen consumed. Upon the whole, I think we have reason to believe, that the base of oxygen gas unites with the blood in its passage through the pulmonary veins. It is also very probable, that a part of the azotic gas respired, is absorbed by the blood. But experiments are still wanting completely to ascertain the fact.*

* The impossibility of making an accurate estimate of the residual air in the lungs, forms a very considerable barrier to the progress of this branch of physiology. May not this difficulty be obviated in some measure, by experimenting upon animals which have not yet breathed. It was my intention to have instituted a series of experiments upon the fœtus received under water from the uterus of brutes, and transferred into jars filled with different gases. In this manner, perhaps we might ascertain the precise changes induced by the air upon the blood, and by the blood upon the air. By experimenting upon large animals, and bringing the placenta into contact with different gases, while the fœtus is immersed under water of a proper temperature, we would in all probability be able to determine what changes the blood undergoes, while passing through the umbilical vessels.

Does the formation of fixed air, eliminated from the lungs, depend upon the union of oxygen with carbon, separated from the venous blood?

Doctor Burdin placed Guinea pigs under a bell-glass filled alternately with atmospheric air, oxygen gas, azotic gas, and hydrogen gas. In all these cases, there was nearly the same quantity of carbonic acid gas disengaged. From this he infers, that the production of fixed air is not owing to the presence of oxygen in the lungs.

As it was impossible to measure the quantity of fixed air contained in the lungs, immediately before the animal was placed in the jars of hydrogen and azotic gases, this experiment cannot be deemed conclusive. A certain portion of oxygen gas must also have existed in the lungs at the moment of introducing the Guinea pig into the jar ; as soon as the whole of the oxygenous gas was consumed, the animal would die for want of fresh air.

With a view of determining this question, I opened a pregnant bitch under water, and transferred one of the fœtus into a jar of pure azotic gas.* The young animal breathed regularly, at long intervals, for the space of ten minutes. It then appeared to be dead, and was taken out. Part of the azotic gas in which it had respired, was agitated with lime-water in a small glass tube. The turbid appearance of the lime-water evinced the presence of fixed air.

Is respiration essential to the evolution of animal heat?

Of all the stimuli that assist in the support of vital action, none is more indispensable than heat. If we examine an infant

* To satisfy myself that this gas contained no oxygen, a small portion of it was added to nitrous gas. No absorption whatever took place. It was then well washed in a solution of caustic pot-ash ; when agitated with lime-water, no precipitation ensued.

just emerged from its mother's womb, we will find that it is as much in want of heat as of air. Soon after birth, however, the necessity for air increases, and the dependance upon external heat diminishes.

In cold-blooded animals, we find the same connection between respiration and the generation of heat. In the frog, the temperature of which seldom exceeds 60° of Farenheit, respiration is slow, and a very small surface of blood is exposed to the action of the air. The spawn of frogs are deposited in water, where but little benefit can be derived from either heat or air. In the eggs of warm-blooded animals, we find a very different order of things. The eggs of fowls during the whole process of incubation are kept at a temperature of about 99°, and receive a continual supply of fresh air.

The greater the natural heat of an animal, the greater is the necessity for air. Accordingly, we find, that in birds, whose temperature is seldom below 102°, the respiratory organs are large. But this increase of respiration is always accompanied by a corresponding increase of circulation. When we diminish the action of the heart and arterial system we lessen at the same time the demand for air. A dog after being bled until the pulsation of the arteries was rendered imperceptible, lived four minutes and a half under water. Another dog of the same age and size, shewed no signs of life after being immersed two minutes. Spallanzani has proven, that animals in the torpid state live almost without respiration. Their circulation was at the same time extremely languid. "He kept a marmot, while in the torpid state, four hours in carbonic acid gas, (the thermometer at 12°), yet it continued to live in this gas, which is so very deleterious, that a bird and a rat, exposed to its influence at the same time, perished instantaneously." The justly celebrated John Hunter observed, while bleeding a lady, that the blood as it flowed from the vein assumed the bright vermilion hue of arterial blood, as soon as a state of fainting was induced.

As respiration and circulation are so inseparably connected, it is difficult to determine which of these two functions has the greatest agency in the production of animal heat. The action of the vessels is unquestionably necessary to the process; but it has been doubted by many respectable physiologists, whether animal heat is at all dependant upon respiration. We will endeavour to give a very brief account of the principal objections which have been made to the opinion, that respiration is the source of animal heat.

De Haen found that the temperature of one of his patients, which during an inflammatory fever had never exceeded 103°, at the time he expired, and for two minutes after, stood at 106°. We cannot conceive this to be an objection of much weight. Respiration continued until the thermometer had risen to 106°. If we admit that the generation of heat ceased with the last expiration, still it cannot be supposed, that any sensible change would be induced in the heat of the body in so short a time as two minutes. That there have been frequent instances of bodies remaining warm for a considerable time after death, there can be no doubt; but what connection can these cases have with life? If we endeavour to explain the fact, our explanation must be founded upon principles common to dead matter. The blood has generally, perhaps always, been found fluid in those bodies which have retained their heat long after death. As it has been proven by Count Rumford, that fluids are bad conductors of caloric, the heat which the blood has acquired during life, will be imparted very slowly to the surrounding substances. If, indeed, life remain, if any degree of motion, however feeble, exist in the arterial system, the fact does not militate at all against our theory of animal heat. For, according to this theory, it is the office of the arteries to separate from the blood a certain quantity of heat imparted to it by the air. We cannot pretend to specify the precise time in which the whole of this heat will be evolved from the blood.

Certain affections of the stomach produce coldness of the extremities while respiration goes on in the usual manner. But these impressions upon the stomach have always a remarkable influence upon the circulation.

The blood in the right auricle has been found warmer than that of the left. From this it was inferred that respiration serves merely to cool the blood in its passage through the lungs. By repeating this experiment, Coleman has indeed shewn, that the first effect of respiration is to cool the blood 2°. But this experiment, as Coleman justly observes, is not unfavourable to the opinion that respiration is the source of animal heat. "For although the heat of the blood in the "right side of the heart exceeded that of the left immediately "after respiration had ceased, yet when 15 minutes had elap-"sed, the temperature of the left auricle was four degrees "greater than the right. This experiment was repeated by "Astley Cooper with the same result, and proves that the blood "in its passage through the lungs had undergone a change "which enabled it to impart heat to the whole system."*

We may conclude then, that as food taken into the stomach supplies the materials from which blood is formed, so air taken into the blood constitutes the pabulum from which heat is evolved by arterial action. That peculiar action by which heat is separated from the blood, may be diminished in one part at the same moment that it is increased in another.

Having given an account of the principal arguments in favour of and against the opinion, that respiration is the source

* "The lungs, says the ingenious Burdin, are a real organ of digestion : they assimilate oxygen gas, and probably a small quantity of azotic gas ; these materials enter into the circulation, and serve for general nutrition and for the production of animal heat." This theory owes its origin to the discovery of Dr. Black, that many substances contain heat in a latent state.

of animal heat; we will proceed to inquire how far irritability depends upon the same process.

This is the most difficult part of our subject. By irritability we mean that property of the living fibre, which enables it to contract upon the application of a stimulus. The precise nasure of this property has eluded the most patient researches of the ablest inquirers. Whether it is the result of vital action; or is the immediate endowment of the Great Author of nature, without the intervention of secondary causes, we cannot pretend to determine. The germs even of large animals may possess a degree of vital action entirely imperceptible by our feeble organs. But however ignorant we may be of the manner in which this principle is first imparted to the body, we are well assured, that the influence of external agents is essentially necessary to its developement and continuance in a perfect animal. We know too that the power of action may be increased or diminished according to the nature of the stimulus applied. Thus, in the experiment of Boyle mentioned in the beginning of this essay, the irritability of a fœtus was increased by respiration. After every other symptom of life had ceased, the heart continued to contract nearly eight hours. In another pup precisely under the same circumstances, except that it had not breathed, the action of the heart was perceptible only for a few minutes. The researches of later physiologists have shewn, that air deprived of oxygen, instead of increasing the irritability of the heart, entirely destroys all power of contraction. The general effect of the application of all other stimulants, except air to living animals, is to produce an exhaustion of irritability in proportion to the action induced. The more sudden the exhaustion of this principle, the more necessary it is that they should be endowed with some power of renewing it. The actions of animals with warm blood are such as tend rapidly to destroy their contractile power. Their lungs are accordingly very capacious and expose to the air a large surface of blood. To elucidate our meaning we will compare the actions of the fœtus in utero with those of the infant after birth.* In the former we find that the heart and arterial system do not make more than sixty feeble pulsations in a minute, whereas in the latter the pulse is much stronger and seldom beats a smaller number than one hundred and twenty in the same space of time. The consequence of this increased action would be a total loss of irritability were it not renewed at the same moment that the increased action takes place. In examining the fœtus of brutes at different periods during gestation, I have always found, that irritability decreases in proportion to the increase of action. The heart of a pup a few weeks after conception is much more tenacious of life than at any later period.

In cold-blooded animals we can trace the same connection between their irritability and the rapidity of their circulation. The action of the heart and arteries, in fact all the motions of the tortoise, are slow. The respiration of this animal is also slow and its irritability is retained long after death. The tortoise buries her eggs under ground, where they are exposed to the influence of no stimulus whatever, except a low degree of heat, and perhaps an extremely small quantity of air. These eggs if placed under a hen would, in all probability, be destroyed by the excessive stimulus of heat; and the hen's egg if deposited under ground, and maintained at a proper temperature, would die for want of air. We may conclude then, that one of the final causes of respiration, is to render the contractile fibre more susceptible of impression, from the different stimuli which support vital action.

* Saumarez in his elements of physiology, page 33, tells us, that he has frequently known the pulsation of the funis not more than fifty strokes in a minute, whilst the maternal pulse was at one hundred.

SECTION III.

EXPERIMENTS AND OBSERVATIONS ON INCUBATION.

FINDING it extremely difficult to procure subjects for the purpose of examining the relation which the fœtus in utero bears to atmospheric air, I directed my attention to the young of oviparous animals. My first inquiry was, whether eggs before incubation induced any change in the external air? An experiment related by Spallanzani is a sufficient proof that they do. "I inclosed," says this excellent philosopher, "a hen's " egg in three cubic inches of atmospheric air. At the end of " some hours, the elevation of the mercury was such, as to lead " me to suppose that a considerable change had taken place in " the air. On transferring the remaining air into the eudio- " meter, I found that the azotic gas remained undiminished, " that eighteen degrees of oxygen had been consumed, and " six and a half of cabonic acid produced."

Being desirous of ascertaining whether this power of abstracting oxygen from the atmosphere increased during incubation, I procured two eggs which had been under the hen from the fourth to the twelfth of May. They were inclosed with nine cubic inches of atmospheric air in a glass bottle with a ground stopple. The bottle was then placed under water heated to 100°. This temperature was maintained for ten hours. A portion of the air was then introduced into the eudiometer and found to contain five per cent. oxygen gas; so that five sixths of the oxygen gas contained in the vessel was consumed by the eggs. One hundred parts of the air were also agitated over lime water in the eudiometer, three parts of fixed air were absorbed. As a considerable part of the fixed air must have united with the water in passing from one vessel into another, I could not ascertain the precise quantity of carbonic acid given out.

A few days afterwards I immersed two fresh eggs in the same vessel with the same quantity of common air. After remaining ten hours at the heat of 100° they were taken out, and one hundred parts of the air were examined as in the last experiment, by leaving it twenty-four hours in contact with phosphorus. At the end of that time nineteen parts of the air were absorbed. From this it appeared, that one third of the oxygenous gas contained in the vessel was consumed by the eggs.

From these experiments it is evident, that an egg during incubation consumes more oxygen than a fresh egg. On examining the air contained in fresh eggs I found, that it consisted of, about one part carbonic acid gas, from five to six parts oxygen gas, and from 93 to 94 parts azotic gas. The quantity of oxygen increases with the increase of vital action in the chick, as will appear by the following statement.

On the 6th day of incubation the air of the egg contained 8 per cent oxygen.

12th . . . . 10 per cent.

14th . . . . 13 per cent.

Does the egg during incubation possess the power of generating heat?

"Having taken some eggs," says John Hunter, "when the "chick was about three parts formed, I broke a hole in the "shell, and introducing the ball of a thermometer, found that "the quicksilver rose to 99½. In some that were addled "I found the heat not so high by two degrees; so that the life "in the living egg assisted in some degree to support its heat."

With a view of ascertaining, whether this power of generating heat be proportioned to the degree of vital action, I made the following experiments.

A thermometer was introduced into an egg which had been six hours under the hen. The mercury rose to 97°, and retained that temperature for nearly three minutes, when it fell to 96°.

Another egg on the sixth day of incubation was then opened and examined in the same way; the mercury rose to 98°, and in three minutes fell to 97½.

From these experiments it appears, that the egg during incubation performs a function very analogous to respiration, and that the quantity of animal heat evolved is proportioned to that of oxygen consumed.

The next step in the investigation was to endeavour, to ascertain how far the irritability of the chick in ovo is dependant upon the influence of air.

I took an egg in the seventy-third hour of incubation and opened it under water at the temperature of 98°. The pulsations of the heart were one hundred in a minute. After nine minutes had elapsed the pulsations were eighty-four in a minute. The colour of the blood underwent a gradual change from a light to a dark red. The egg was now taken out of the water and exposed to the air.* The blood immediately resumed the light vermilion hue which it possessed when the egg was first opened. After it had been exposed about half a minute to the air the pulsations were again counted; they were ninety-eight in a minute. For a few minutes after the egg was a second time immersed under the water, the pulsations were from ninety-eight to one hundred and two; they gradually became weaker and less frequent, and the blood again acquired a dark colour. After fifty-four minutes had elapsed, the action of the heart ceased.

SECTION IV.

ON THE RESPIRATION OF THE OXYGENATED MURIATIC ACID.

SOON after it had been proven, that the oxygenous portion of atmospheric air when taken into the lungs exerts a very ex-

* The temperature of the air was at 64°.

tensive influence upon the whole system, it was inferred that other substances which contain the base of this gas, would have the same effect when applied to different parts of the body.

The nitric and oxygenated muriatic acids, in common with several other substances of a similar nature, have been exhibited with a view of oxygenating the system. They were all used upon the supposition, that when applied to the inner surface of the stomach and intestines, the same change would be induced in the blood circulating through these viscera, as is effected in the same fluid while passing through the pulmonary veins. Although these hypotheses are entirely destitute of foundation, yet they have led to the discovery of some useful truths: for however ignorant we may be of their modus operandi, the nitric and oxygenated muriatic acids, are valuable articles of the materia medica.

The oxygenated muriatic acid in the gaseous state, has been lately recommended as a substitute for atmospheric air in the process of resuscitating drowned persons. The large proportion of oxygen which enters into the composition of this gas, the readiness with which some combustible bodies are inflamed when thrown into vessels containing it, the increase of vital action which it evidently induces in vegetables, all tend to favour the supposition, that it would prove an useful auxiliary in restoring suspended animation.

In the year 1803, Citizen Potel, while engaged in preparing some oxygenated muriatic acid gas, observed, that several rats which had been drowned and accidentally exposed to the action of this gas, were very soon revived; he repeated the experiments upon other animals with the same success.

After several unsuccessful attempts to resuscitate drowned animals in the manner described by Citizen Potel, I made the following experiments, with a view of ascertaining, what quantity of this gas could be taken into the lungs with safety.

A mouse was introduced, under water, into a jar containing sixteen cubic inches of pure oxygenated muriatic acid gas. His respiration immediately became extremely laborious. The animal died in twenty-one seconds. On opening the thorax, we could not perceive the smallest mark of irritability in the heart.

Another mouse was placed in a vessel containing equal parts of oxy-muriatic acid gas, and common air. He died in thirty seconds. A third mouse was exposed in the same vessel, to an atmosphere composed of one part oxy-muriatic acid gas and eighty parts of common air. After three minutes had elapsed, the mouse was taken out, and exposed to a current of fresh atmospheric air. Two hours after being removed from the vessel, he died.*

With a view of comparing the effects produced by this gas upon the circulation with those of atmospheric air, I repeated the experiment of Vesalius. After raising the sternum of a

* These experiments were repeated on larger animals, with the same result. The respiration of this gas, even in very small quantities, in every instance produced death.

When injected into the stomach, its effects were very different. A dog experienced so little inconvenience from it, that he ate a piece of meat immediately after his stomach had been distended with oxy-muriatic acid gas diluted with an equal quantity of atmospheric air.

About fifteen cubic inches of oxy-muriatic acid gas, with thirty of common air, were injected under the skin and cellular membrane of a cat. It excited great pain, but did not destroy the life of the animal. She recovered in the course of a few days.

It was my intention to have instituted a series of experiments, with a view of ascertaining, whether atmospheric air, and the different gases, exert any immediate influence upon the blood, while circulating in other parts of the body, as well as in the lungs. In this way, perhaps, we might be enabled to determine in what manner the miasmata which induce the different autumnal forms of fever, are first introduced into the system. The exhalations from putrid animal and vegetable substances, could be very easily applied alternately to the stomach, the skin, and the lungs of different animals.

dog, and opening the pericardium, a tube was adapted to the trachea; as soon as the action of the heart had nearly ceased, the lungs were inflated with atmospheric air; the heart immediately began to contract with considerable force, and the change of colour in the blood of the pulmonary veins, so well described by Hooke and Goodwin, was very evident. On omitting the inflation, the heart very soon assumed the same feeble state of contraction, which it possessed before artificial respiration was begun. The lungs were now inflated with equal parts of oxymuriatic acid gas and common air. The heart performed two or three feeble convulsive motions, very different from the regular contraction induced by the inflation of atmospheric air. The blood in the pulmonary veins, and in the left side of the heart, was much darker than usual; but what particularly attracted my attention, was the slowness, and apparent difficulty, with which the gas was discharged from the lungs. When inflated with atmospheric air, they collapsed as soon as the syringe was withdrawn from the tube in the trachea; but when the oxygenated muriatic acid gas was used for the purpose of inflation, it required a much greater force to fill the lungs, and but little more than half the quantity propelled into them was returned. The lungs, in ordinary respiration, are certainly passive, but may not these viscera, when inflamed, or when any acrid stimulus is applied to them, possess a contractile power? I confess my inability to give a satisfactory answer to this question. "Mallem quidem cautam ignorantiam confiteri, quam falsam scientiam profiteri."